Optimization of HTS Tape Coil Design

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Introduction

HTS RF coils can significantly improve the SNR of MR images [1]. So far most of the HTS RF coils are fabricated into films [2] by YBCO materials. As a different form of HTS material, Bi (2223) tapes show the potential in MRI application due to their much easier fabrication, frequency adjustment and much lower cost than HTS films. A theoretical model is set up to discover the relationship among Q, coil size, solder joint and resonant frequency. Several coils with different sizes and resonant frequencies were fabricated and the model was verified by the measurements of their Qs at 77K. The model fit the experimental results well and would be helpful in HTS coil design and SNR estimation.

Theory and methods

To fabricate an RF surface coil, the tape (with width of 3.5mm) is bent into a circle whose diameter should be larger than its critical diameter. A non-magnetic capacitor with high Q (>2000) is soldered directly at both ends of the tape to form a LC resonant loop.

$$Q = \frac{f}{\Delta f} = \frac{\omega}{\Delta \omega} = 2\pi f \frac{L}{R} = \omega \frac{L}{R} \qquad (1)$$

For a surface coil, its Q is often given by equation (1) [3], where ω, L and R denote resonant frequency, inductance and coil resistance respectively. The inductance is determined by its geometry. The resistance of the coil comes from the HTS tape and the solder joints. When the coil works at 77K, the tape comes into superconducting status, thus the total resistance almost comes from the solder joints. The skin effect should be considered in the calculation of the resistance. Expression for Q can finally be presented by equation (2).

$$Q = \omega \frac{L}{R} = \left(\frac{A}{\mu_0}\right)\left(\frac{a^2 N^2 K'}{b}\right)\left(\frac{p}{l\sqrt{\rho}}\right)\omega^{1/2} \qquad (2)$$

In equation (2), A, K' are constants related to the tape configuration, μ_0 is the permeability in free space, a is the radius of the coil (for a multi-turn loop, a is the mean radius of the turns), b, the width of the tape, N, the total number of turns for a multi-turn coil, ρ, the resistivity of the solder material at 77K, l and p, the length and the cross section of the solder respectively. If the solder joints are considered to be uniform, equation (2) can be simplified to equation (3).

$$Q \propto \frac{a^2 N^2 K'}{b}\omega^{1/2} \qquad (3)$$

To verify the theoretical model, we fabricated several coils with different sizes resonated at different frequencies, and measured their Qs in liquid nitrogen at 77K. The experiment setup for Q measurement is shown in Fig-1. The Ag sheath on the HTS tape should be etched out first to avoid the screening of the superconducting phase from RF signal. Then it was wound around the supporter to fix its position and was immersed into the liquid nitrogen. A 2-inch pick-up coil connected to an HP 8735C network analyzer was used to couple the RF signal. This mutual inductive coupling was also used to match coil impedance by adjusting their relative positions between the pick-up coil and the HTS coil. The Q can be read from the network analyzer directly. The experiment data to verify equation (3) are listed in Table-1. These data fit the linear relationship in equation (3) successfully. The errors are mainly due to the non-uniformity of the solder joints.

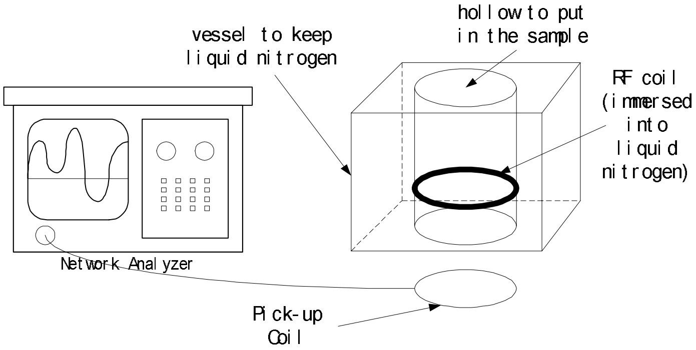

Fig-1 Experiment setup for Q measurement

Coil	Diameter (2a, cm)	K'	Frequency (MHz)	Q	$a^2K'\omega^{1/2}/Q$ ($cm^2/\mu s^{1/2}$)
Coil 1	56	~0.1414	72.08	809	2.9162
Coil 2	65	~0.1236	125.82	1270	2.8903
Coil 3	65	~0.1236	12.91	396	2.9692
Coil 4	127	~0.0839	8.92	861	2.9416

Table-1 Experimental verification for equation (3)

Conclusion and discussion

There are two ways to improve Q of HTS tape: first, to increase the coil radius because its square is proportional to Q; second, to increase frequency because Q is proportional to the square root of the resonant frequency. In addition, Q can be further enhanced by using the solder with low resistivity or making the solder joints as thin as possible, to decrease their resistance.

Based on our experiments, a 5-inch HTS tape has shown an over 6-fold Q improvement to a copper coil with the same size at 8.92MHz. Thus, this HTS tape coil could be expected to have a SNR improvement by a factor of 2.5 [4].

References

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